DIGITAL SUBSTATION TEST SITE

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With the test site developed at a live experimental substation, it is possible to simulate in real time the disturbances occurring in an adjacent electrical network and at the power facility itself. This, in turn, makes it possible to considerably shorten the time of implementation of new technologies when testing the functional performance of equipment and to analyze different options of a local area network for substations of any voltage class.

Keywords: digital substation; IEC 61850; DSS test site (DSS TS); process bus; station bus; testing and simulation facility; real-time digital simulator (RTDS).

The optical transformers of the Digital Substation Test Site in R&D Center at FGC UES

INTRODUCTION

On October 3-5, 2017, JSC R&D Center at FGC UES hosted an important international event in the field of development of digital technologies in the power industry held in Moscow and entitled International Conference "Digital Substation. Standard IEC 61850." The conference was organized jointly with DNV GL (formerly KEMA). The general partner of the conference was PJSC FGC UES, part of PJSC ROSSETI Group of Companies; a great contribution to the event was made by Russian NC of CIGRE. The conference was attended by more than 230 Russian and foreign specialists from 16 countries.

The event was followed by a discussion emphasizing that the main objective of the conference was to establish a Center of Competence serving as a joint platform for discussing issues pertaining to the implementation of the Digital Substation technologies, and the objective was achieved. Participants of the conference noted the high level of organization, relevance and completeness of the topics covered.

It is no coincidence that JSC R&D Center at FGC UES was selected to host such an event, given the following developments:

- On assignment from PJSC FGC UES, jointly with other organizations, the FGC Digital Substation Simulator Concept was developed in 2011–2012.
- In 2010, on the basis of the 110 kV substation, JSC R&D Center at FGC UES built Russia's first digital substation, where IEC standard 61850 (8-1 and 9-2 LE) was implemented for the transfer of measured cycle parameters (currents and voltages) at the 110 kV side from optical combined CTs and VTs in a digital form to the SS control system and for sharing data between secondary switching devices: the Digital Substation Test Site (DSS TS).

As part of the DSS TS, an array of R&D efforts was dedicated to the

STRUCTURAL SCHEMA OF DSS TS BY JSC R&D CENTER AT FGC UES

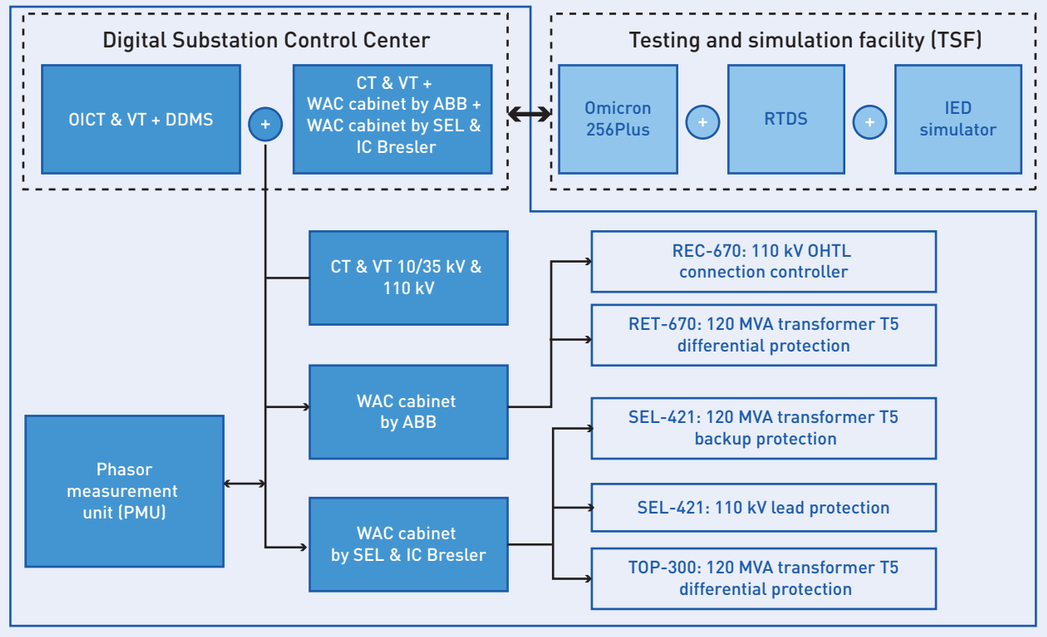

Fig. 1

development of the Digital Substation (DSS) components:

1. Merging units that convert analog signals from instrument CTs and VTs into digital streams as per IEC 61850-9-2(LE),
2. High voltage circuit breaker field converter (HVCBFC), which converts digital streams (IEC 61850-8-1) into discrete signals to control the HV circuit breaker drive,
3. Pilot models for the analysis of DSS LAN digital streams to be used for commissioning and day-to-day operation:
– suite for the analysis of communicative interactions of DSS components,
– suite for the evaluation of dynamic characteristics of communication equipment (digital switches) and network characteristics of DSS secondary switching digital terminals.
4. The DSS TS is the ground for:
– various types of tests of equipment carried out with utilization of the Digital Substation technology;
– guided technical tours, with a curriculum devised for personnel training of related companies and works performed at different levels by representatives from educational institutions;
– international collaboration on the certification of equipment to the IEC 61850 standard.

HISTORICAL BACKGROUND: WHO NEEDS THE DIGITAL SUBSTATION TEST SITE (DSS TS)?

In 2010–2011, by order of Federal grid company, by three organizations – JSC "NTC of electric power industry" (currently JSC "NTC" Federal grid company"), JSC" Institute "Energosetproekt "and JSC" Continuum "developed the Concept of software and hardware complex (PAC)" digital substation ENES". At the same time, work was started on a pilot project called "Creation of a pilot test site for testing and complex testing of the main elements and subsystems of the digital substation, as well as complex technical solutions for process control". It was proposed to create a test site on the basis of the existing 110 kV experimental substation of JSC "STC FGC UES".

TEST SITE — 110 KV SWITCHYARD, RTDS, SSCC, TRAINING CENTER (SPECIAL CLASSROOM)

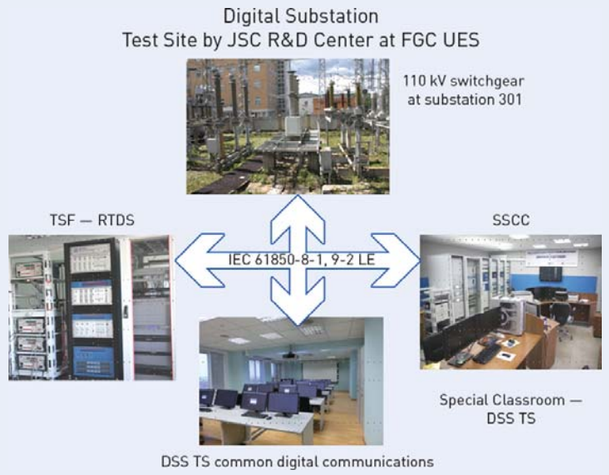

Fig. 2

The introduction of new technology into operational practice, as a rule, is carried out through the mechanism of pilot development of equipment. This leads to the fact that an additional, essentially experimental backup circuit is created at the facility, the equipment of which operates on the signal, which makes any project more expensive and creates additional problems for operating personnel.

The equipment, developed with using the new technology, can to work for a long time in the mode of monitoring disturbances in the external electrical network and at the substation, without triggering even the signal, in the absence of disturbances in the functioning of equipment in the electrical network and in the substation, therefore to obtain a full operational experience with such the method of mastering technology in a relatively short period (quarter, semester, year) is extremely difficult.

DSS TS MISSIONS

The DSS technology is based on the utilization of equipment developed in accordance with IEC 61850, which describes the information models of primary and secondary equipment, classifies the levels of the substation automation system, and sets the rules for data interchange between the devices (process bus, station bus, so-called "digital circuits") included in the substation automation system.

When developing the DSS technology, it is necessary to address a number of interrelated challenges on a holistic basis. First of all, a method for applying the provisions of IEC 61850 should be devised and tested in practice. In other words, it is necessary to create a DSS prototype, verify technical solutions on test specimens, and work out recommendations for industry-related organizations on how to apply the innovative technology.

In addition, the DSS TS should play the role of an academic educational center to promote the DSS technology into operational practice. The experience accumulated with the DSS prototype operation should contribute to the development of normative documents pertaining to the design, commissioning, and operation of similar facilities.

The most significant tasks for which the DSS TS is intended include testing of the equipment designed in conformity with IEC 61850 for interoperability: optical current and voltage transformers, analog and discrete signal converters, and intellectual electronic devices (IED), which are analogs relay protection and emergency control automation terminals.

This technology is based on the transfer of data streams in an Ethernet-based communication environment. In this case, the most critical issues are to comply with the standard's requirements to delivering messages of various categories within specified timeframes and organize synchronous operation of devices.

The main technical solutions for the components of the DSS technology, tested at the test site DSS on the prototype of software and hardware complex DSS, form the basis for the development of typical solutions for substations of various voltage classes.

To accelerate the introduction of equipment created using the new technology, it was necessary to create an active test site that simulates perturbations on the equipment under test to verify the claimed technical characteristics. In addition, in the case of equipment installation at an operating power facility (to check immunity of the equipment's from electromagnetic interference of various types, switching overvoltages, etc.), it becomes possible to conduct tests in conditions in which this equipment will subsequently work.

An active test site must have a testing and simulation facility (TSF) to simulate disturbances (different types of short circuits, sudden shutdowns of primary equipment at the facility and in the adjacent power network), which should be applied to the secondary equipment under test, i.e., this means that the TSF should produce distur-

In 2010-2011, commissioned by JSC FGC UES, JSC R&D Center at FGC UES, JSC Institut Energosetproekt and JSC Kontinuum developed the FGC Digital Substation Simulator Concept

SUITE FOR CHECKING THE DYNAMIC BEHAVIOR OF A COMMUNICATION NETWORK

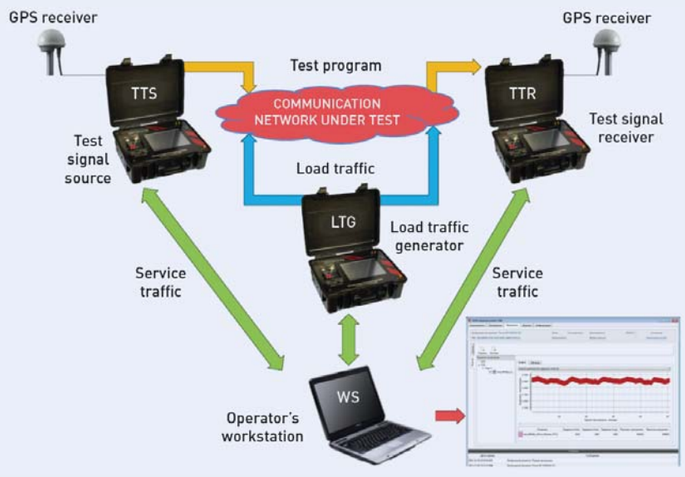

Fig. 3

bances in three phases in real time. In addition, the TSF should be able to produce disturbances both in analog form, such as instantaneous values of currents and voltages, and in digital form in accordance with IEC 61850 9-2LE (to implement the process bus).

The DSS TS development includes creation of a digital circuit for primary instrument equipment (current transformer (CT) and voltage transformer (VT)) and secondary equipment in combination with the testing and simulation facility. This approach allows verifying the technical solutions for the layout of secondary equipment, its information links with primary equipment and with upper and medium levels of the power facility's process control automation system (verifying the communication environment architecture for the process bus and the station bus) as well as the functional characteristics of the equipment itself in the event of different types of disturbances in the external network within a reasonably short time, and, finally, formulating requirements to the engineering solutions. When considering the possibility of implementing this technology at real power facilities, it was assumed that it would be necessary to add to the existing main microprocessor-based and backup security terminals that use analog inputs from conventional electromagnetic CTs and VTs a third experimental digital circuit with protections receiving inputs in digital form (in accordance with IEC 61850-9-2LE) and working on that signal, which would increase the project cost considerably. When conducting experimental activities using the active test site for different model options of primary and secondary equipment, it is possible to obtain a set of typical circuits for station buses and process buses and later on perform the implementation at power facilities without additional experimental 'digital' standby circuits. Additionally, compatibility will be verified with the existing certified equipment compliant with IEC 61850.

DSS TS STRUCTURE AND EQUIPMENT CONFIGURATION

JSC R&D Center at FGC UES began constructing the test site in September of 2010. The DSS TS consists of:

- 110/10 kV substation No. 301 — live electrical installation with a specialized double-wound transformer consisting of a three-phase group of 40 MVA, with a switchable second winding allowing to obtain 10, 20, 35, and 90 kV. Two groups of optical measuring current and voltage transformers (CT and VT) are installed at 110 kV substation switchgear);
- the DSS control center (SSCC), with a digital data measuring system (DDMS) including four intellectual electronic devices (IED, in terms of IEC 61850), data computations complex (DCC) based on KOTMI-2010 SCADA, with transformer digital protection and 110 kV circuit breaker controller installed (using equipment from reputable foreign and domestic manufacturers of wide area control and emergency control automation devices: ABB, SEL, IC Bresler, Alstom-Grid, Ekra);
- DSS TS laboratory equipped with a testing and simulation facility (TSF) comprised of: real-time digital simulator (RTDS); OMICRON and PETOM 61850 test units; software digital terminal simulator (IED) with simulators of digital data streams for loading the process buses and station bus during 'storm' tests and other types of tests. Communication environments of the SSCC of substation No. 301 and the laboratory are linked by a high-speed fiber optic communication channel.

To create a state-of-the-art TSF allowing obtainment of a full-fledged model of a complex power system, including ultrahigh voltage substation models, it is necessary to focus on powerful multiprocessor systems that have internal data buses of at least 1 GB supporting IEC standard 61850 in respect of the process bus and enable streaming of quick messages (GOOSE). Such software is RTDS, which is manufactured by the company with the same name in Canada (Winnipeg) and applied in dozens of countries worldwide.

The RTDS is designed specifically to simulate operation modes of power systems and test the secondary switching equipment intended for control and protection. Multiple analog and digital channels of input and output signals are transmitted via optical links and allow making diverse connections of equipment under test with the simulator with high accuracy.

In 2015, the formation of the DSS TS infrastructure was completed; a training center (hereinafter the Special Classroom) was added to the commissioned sections of the site (CT and VT at the 110 kV switchyard, SSCC, RTDS).

The Special Classroom is fitted with computers and multimedia equipment designed for 10 trainees, with a designated place for the instructor, and is an integral part of the DSS TS, featuring a common communication environment (SSCC – laboratory part with TSF — the Special Classroom).

Additionally, the Special Classroom is intended for demonstrating the performance of DSS equipment, training, and testing the equipment designed in accordance with IEC 61850 (DSS components). A training curriculum has been devised for introducing the staff of operational, commissioning and design organizations to the DSS technology and approved by PJSC FGC UES.

R&D CARRIED OUT DURING THE DSS TS CREATION

From the standpoint of managing communication at the DSS, devices of all levels connected to the communication network are components of communication interaction along with the network equipment, such as switches, data reception and transmission redundancy units (Red Box devices), and transponders. Communication interaction across the DSS network is a process of reception and transmission of messages determined by communication protocols within the DSS in accordance with IEC 61850 standards. The required message formats and delivery time limits are regulated by a number of standards:

1. communication message formats — by IEC 61850-8-1/9-2LE;
2. total communication message transmission times — by IEC 61850-5;
3. time of message transmission directly through the communication network and the communication subsystems of the source and receiver — by IEC 61850-10 [2].

In the process of DSS TS creation, following JSC R&D Center at FGC UES technical requirements, JSC ITC Kontinuum developed a specialized instrumental system for multilevel testing of communications between RTDS components of the DSS. This toolbox includes two testing and simulation facilities (TSF) intended for enabling testing at all levels of the OSI/ISO (open systems interconnection) basic reference model, from the physical to application level:

- suite for the analysis of communicative interactions of DSS RTDS components [3];
- suite for the verification of dynamic behavior of communication interaction of DSS RTDS components [3].

With these suites, it is possible to determine the following characteristics of communication interaction:

LIST OF TEST BENCH EQUIPMENT

№	Manufacturer	Description	Subsystem
1	NxtPhase	NXVCT	Optical CT&VT
2	NPP Mikronika	SO52-MUA	Analog signal BC
3	ITC Kontinuum +	CT&VT field converter	
4	NPP Mikronika	SO52-MUIO	Discrete signal BC
5	IC Bresler	TL 2607.XXA	WAC (graded protections)
6	SEL	SEL-421	WAC (Breakers Control Automation)
7	Schneider Electric	Micom P444	WAC
8	NPP Mikronika	SO52-PB	DCS
9	Landis&Gyr	ZMQ802C	AUMIS
10	ITC Kontinuum +	PMU	SPM
11	NPP Mikronika	SO55	DCS upper level
12	NPP Mikronika	SYNDIS-RV	SCADA

Note:
- BC means process bus coupler (analog/discrete);
- SCADA (Supervisory Control and Data Acquisition) is a set of programs designed for development or real-time operation of systems for acquisition, processing, displaying and archiving information on an object of monitoring or control.

Table 1

1. time of delivery of information messages in various operating conditions of the communication equipment;
2. reliability of delivery of information messages in various operating conditions of the communication equipment;
3. information message format and its conformity with IEC 61850-8-1/9-2LE;
4. information message transmission regulation;
5. information message publication delay (latency);
6. statistical analysis of message streams;
7. test traffic source (TTS);
8. test traffic receiver (TTR);
9. load traffic generator (LTG);
10. operator's workstation (WS).

Packages for analyzing and checking the dynamic behavior of communications between DSS RTDS components are built on a common engineering platform focused on the operation with high communication load levels typical for a digital substation. A typical computation error of temporal characteristics of communications stays within a few tens of nanoseconds, which allows determining with high accuracy the dynamic characteristics of communication, such as delay of publication and time of delivery of communication messages.

Following the technical guidelines of JSC R&D Center at FGC UES and JSC Energosetproekt, jointly with LLC Laboratory DEP, an adapter was designed (high voltage circuit breaker field converter, or HVCBFC) for operation with the HV breaker drive.

END-TO-END TESTING OF SECONDARY SWITCHING EQUIPMENT DESIGNED FOR THE DSS TECHNOLOGY

COMPATIBILITY TESTING OF EQUIPMENT FROM DIFFERENT MANUFACTURERS

First end-to-end tests were performed at the Digital Substation Test Site of JSC R&D Center at FGC UES under the Program approved by PJSC FGC UES (tests of the secondary switching equipment designed in accordance with IEC 61850 introduced by JSC Novointech).

Purpose of the tests:

- To test the technical solution for building the digital substation segment in accordance with the technical requirements of the "Creation of a smart grid at external power supply facilities of the Elga coal mine (Elgaugol cluster smart grid)" project at the 220/35/10kV Prizeyskaya substation on the 220kV Prizeyskaya-A OHTL.
- To verify the joint operation of IEDs from different manufacturers on the station bus and the process bus as per IEC 61850-8-1. Joint operation on the station bus means: successful interchange of GOOSE messages (an analog to discrete signals) among IEDs of different subsystems of the digital substation with satisfactory temporal characteristics of data reception and transmission. Joint operation on the process bus means that a process bus source from one manufacturer should publish a digital stream in the network in accordance with IEC 61850-9-2LE, and the process bus receiver from a different manufacturer should perform properly using the published data stream.

STRUCTURAL DIAGRAM OF JOINT OPERATION TESTING UNDER THE IEC 61850-8-1 PROCEDURE (GOOSE MESSAGES)

Fig. 4

COMPATIBILITY OF RETOM-61850 WITH DEVICES SUPPORTING THE IEC 61850 STANDARD FROM DIFFERENT MANUFACTURERS

№	IED Manufacturer	IED Name	Subsystem
1	Schweitzer Engineering Laboratories, Inc	SEL-421	WAC
2	IC Bresler	TOP 300	WAC
3	ABB	RET670	WAC
4	Alstom	MiCOM Alstom P645	WAC
5	Ltd EKRA Research and Production Enterprise	Ekra 2704 562	WAC
6	JSC ITC Kontinuum	PMU-101	SPM
7	Modern Measurement Systems, Inc.	DPM-121	IP

Table 2

- To benchmark the behavior of three different digital stream sources as per IEC 61850-9 2LE and record their characteristics; test the technical solution of creating the process bus in accordance with IEC 61850 from two sources with different working principles: an optical current and voltage transformer, and a process bus coupler; verify the proper performance by IEDs of wide area control (WAC) subsystems, digital control system (DCS), automated utility metering information system (AUMIS), and synchronous phasor measurements (SPM) of their functions while working with the process bus created by an optical current and voltage transformer and process bus couplers in conformity with the functional requirements.

The following equipment was used for the tests (Table 1).

Fig. 4 illustrates one of the test schematics for the DSS segment.

Below is a fragment of the test program for checking compatibility of DSS segment devices in transmission and reception of GOOSE messages.

The most significant tasks for which the DSS TS is intended include testing of the equipment designed in conformity with IEC 61850

Test procedure:

1. GOOSE message publication mode
   - Exporting ICD/CID/SCD files.
   - Concordance of the published GOOSE DataSet header with the ICD/CID file.
   - Publishing GOOSE DataSet with different VLAN tags.
   - Publishing GOOSE DataSet with FCDA-type data.
   - Publishing GOOSE DataSet with FC-type data.

a) Data set with ST (status) functional limitation.

b) Data set with MX (measurement) functional limitation.
   - Switching the device to test mode.
   - Activating/deactivating the GoEna block.

2. GOOSE message reception mode
   - Correct reception of GOOSE data set in normal and test modes.
   - Behavior of subscriber IED in test mode.
   - Behavior of IED on connection loss.
   - Behavior of subscriber IED if key attributes of the message are changed.

A punch list pertaining to the equipment performance was compiled during the testing, since due to the deviations of the software from the standard, compatibility of data exchange was achieved not in all of the test modes. Reports on the experiments carried out during the testing were submitted to the customer who forwarded the punch list to the equipment manufacturer to resolve the issues.

TESTS OF INNOVATIVE ENGINEERING SOLUTIONS FOR DSS TECHNOLOGY

LLC LISIS recommended a new conceptual approach to designing protection and emergency control systems: instead of a conventional automation system, which is a combination of multiple devices of different intended uses (WAC, EC, fault location, emergency event recorders), a unified integrated computational system needs to be created. Such a system is based on cutting-edge

information technologies, implementing functional subsystems that are combined into a single software suite with unified data input points instead of multiple distributed hardware tools. This project is called iSAS [4].

While preparing the iSAS hardware and software package (HSP) for certification, tests were conducted at JSC R&D Center at FGC UES for combined operation of the computational system with other IEC 61850 devices and functional tests of wide area control and process automation subsystems of the 35 kV switchgear.

Development of the iSAS was initially intended for a pilot automation and protection project at the 35 kV switchgear of the 220 kV Elgaugol substation.

All tasks are performed by a single iSAS system installed at one server. Data exchange between the primary equipment with SAMU installed in cubicles and the computational system is performed through a communication environment.

In this project, the iSAS should provide control and protection for 13 connections and two sections of 35 kV buses.

The iSAS package was tested at JSC R&D Center at FGC UES in accordance with the test program.

As part of the project, a working prototype of the system was built with the following functionalities:

- Reception and processing of performance data from 20 connections in the IEC 61850-9-2LE format (Sampled Values).
- Control of the substation primary equipment with up to 20 connections by IEC 61850-8-1 protocols (GOOSE and MMS).
- Protection algorithms are implemented for switchgears of voltage class up to 35 kV (simultaneous protection of 20 connections):
- Current protections (phase-to-phase cutoff, overcurrent protection, earth fault protection)
- Voltage protections (over-/under-voltage relays)
- Differential protections (DBP)
- Remote protection of lines
- Configuration of the system using the Substation Configuration Language (SCL, IEC 61850-6)
- Graphical user interface for online control
- Alarm logging subsystem with a possibility of saving to a Comtrade file

The tests were performed in steady-state and transient conditions.

At the first stage, the following was checked in steady-state conditions:

- functions of data transfer by IEC 61850-8-1 protocol;
- functions of data reception by IEC 61850-9-2LE protocol;
- functions of automatic and operational equipment control;
- information display function;
- overvoltage relay function.

At the second stage of the testing, the following WAC and automation functions of the iSAS were checked:

- differential bus protection (DBP) of 35 kV buses 1 and 2;
- two-stage remote protection (RP) of overhead lines;
- two-stage definite time overcurrent protection (OCP) of overhead and cable lines;
- two-stage definite time overcurrent protection of the auxiliary transformer;
- two-stage definite time overcurrent protection (OCP) of the bus section breaker;
- two-stage definite time overcurrent protection (OCP) of local switches triggered by minimum voltage and negative sequence voltage;
- undervoltage protections;
- automatic load transfer on the bus section breaker;
- automatic re-closure of 35kV overhead lines;
- OL-1 circuit breaker failure protection;
- bus section breaker failure protection;
- emergency event recording (by oscilloscope functions and alarm log records).

Generally, when a new technology is introduced into operational practice, it is achieved through a pilot equipment trial tool

The network's three-phase model was built on the RTDS TSF.

The protection and automation functions were tested with simulation of short circuits of various types, including double short-circuits in different network points as well as with energized equipment. Duty cycles were tested both with an isolated operation of 35 kV sections and with the section breaker switched on. Transients in case of short circuits near the buses were accompanied with saturation of current transformers. On the whole, all of the tested protection and automation functions were working properly. Some individual imperfections of the software revealed during the testing were promptly rectified.

TESTS OF INDIVIDUAL DEVICES TO BE USED AT DSS

In addition to end-to-end testing at the DSS TS, individual devices and technical solutions are tested.

To carry out the commissioning when designing new equipment and creating a 'digital substation' at power facilities, it is necessary to use special test devices that can generate and receive streams of digitized instantaneous values (acc. to IEC 61850-9.2LE), send, receive, and analyze logic signals in GOOSE messages (acc. to IEC 61850-8.1), and measure the temporal characteristics of WAC, EC, and other devices.

One of such devices is the RETOM-61850 digital test unit designed by SPE Dynamics.

RETOM-61850 was tested at the Digital Substation Test Site of JSC R&D Center at FGC UES where the digital tester was examined for compatibility with other substation components and its features were benchmarked with foreign analogs available on the market.

The test results demonstrated that the RETOM-61850 digital test unit (technical specification TU 4042-032-13092133-2012) is compatible with other components of the digital substation of the test site of JSC R&D Center at FGC UES in terms of operation under protocols of IEC 61850-8-1 (GOOSE) and -9-2LE (SV).

The characteristics obtained from benchmarking the RETOM-61850 digital test unit (technical specification TU 4042-032-13092133-2012) with the Omicron CMC-256 Plus test installation and RTDS real-time simulator suggest that the RETOM unit is compliant with the stated features of compatibility with the IEC 61850 equipment.

SAMPLES OF CERTIFIED EQUIPMENT AND A FRAGMENT OF A LEVEL A CERTIFICATE

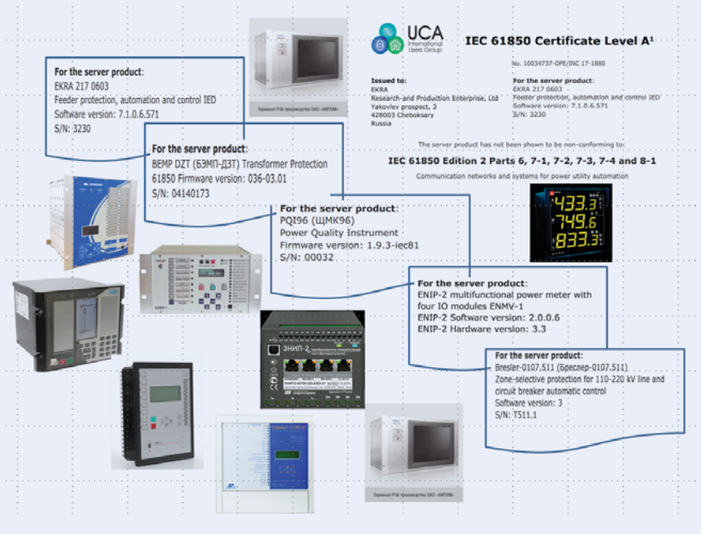

Fig. 5

CERTIFICATION OF MADE-IN-RUSSIA PRODUCTS INTENDED FOR DSS TECHNOLOGY APPLICATION

The DSS technology is based on IEC 61850, which interlaces the data models of primary (switching equipment, power transformers, etc.) and secondary equipment (wide area protection and automation, remote control, power metering, etc.) of electrical power facilities. The standard defines the rules of data exchange (protocols) between the equipment of different levels of the substation control system. Originally, the standard contained 10 chapters. Currently, it is being revised in order to include new types of secondary equipment and eliminate ambiguous interpretation of certain provisions. As of now, its first and second editions are applicable. One of the most important objectives of the standard is to ensure compatibility of equipment from different manufacturers. The product certification procedure is intended to achieve it.

The Russian industry that manufactures secondary equipment began mastering the DSS technology in the late 2000s. Today, numerous companies produce secondary switching equipment of various types that fully or partially conform to the

TESTING INFRASTRUCTURE OF JSC R&D CENTER AT FGC UES

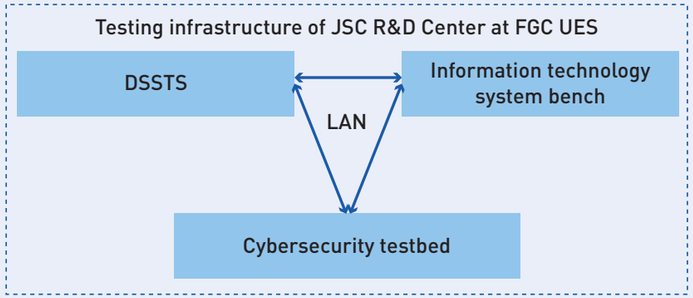

Fig. 6

IEC 61850 standard. To ensure compatibility of equipment at power facilities and guarantee uninterrupted data exchange between control system levels (in conformity with technical requirements), it should be certified for compliance with the standard in its first or second edition.

Utilities Communication Architecture International (UCA) Users Group (hereinafter UCAiug) defines the rules for checking (certification testing) manufacturers' equipment for conformity to the standard (chapter 10 of the standard determines the scope of testing). The international company DNV GL Energy (DNV GL) includes the UCA-accredited test laboratory KEMA Nederland B.V. (until October 2016 it was a standalone business unit responsible for certification of equipment built in accordance with IEC 61850) is authorized by UCAiug to develop testing software applied in certification tests.

Since 2014, KEMA Nederland B.V. (presently DNV GL Energy) has been cooperating with JSC R&D Center at FGC UES in the area of managing and conducting certification tests.

For this purpose, JSC R&D Center at FGC UES carried out a number of activities:

- acquired licensed testing software for certification testing;
- trained its staff in the fundamentals of the testing standard and methodology using the delivered software with assistance from the KEMA Nederland B.V. laboratory. After the training, the personnel completed tests (with positive outcomes);
- concluded an agreement on technical support and updates of the testing software.

These efforts qualified JSC R&D Center at FGC UES to perform preliminary testing of equipment for compliance with IEC 61850.

As part of the cooperation efforts, the parties have agreed that certification of equipment at JSC R&D Center at FGC UES will be made in two stages:

The first stage of preliminary testing will be carried out by the personnel of JSC R&D Center at FGC UES, while the second stage of certification testing will be carried out together with a DNV GL test engineer.

The second stage of certification testing will be performed together with the DNV GL test engineer and an applicant. If the certification tests are successful, the applicant (manufacturer of the products) will be awarded an international level A certificate allowing international distribution of products.

The international organization UCA will issue a level A certificate only if certification tests were carried out by an independent laboratory accredited by UCA (non-related with manufacturers or consumers of the products in question).

BRIEF DESCRIPTION OF BUSINESS PROCESSES OF PRELIMINARY AND CERTIFICATION TESTING

The certification process consists of several stages:

1. Preparation for testing conformance to IEC 61850 (pre-tests).

At this stage, the applicant will prepare documentation for the unit: complete a number of forms (PICS, PIXIT and MICS – determined by the standard), configure the unit, and submit it to JSC R&D Center at FGC UES.

Based on the documentation submitted to JSC R&D Center at FGC UES, a testing plan will be devised and presented to the applicant for approval. Once the plan is approved, preliminary tests are performed, errors in the implementation of the standard are identified, and test reports are submitted for elimination of deviations, if any (this is an iterative process). After the flaws are remedied, the next stage, which is certification testing, will begin.

2. Certification testing

In accordance with the certification testing plan, the unit's software is tested for conformity with the standard. The scope of certification tests is determined in the list set forth in chapter 10 of IEC 61850 (tables 1-33) [6] and the approved testing plan. At this stage, the DNV GL test engineer and the applicant's representative are present. Reports are generated for each type of a test during the testing process.

3. Documentation

At this stage, a report on the tests performed is compiled and the wording of a level A UCA certificate of conformance is formulated. The certificate is sent in an electronic format to the applicant for review. Once the applicant has approved the certificate's wording and confirmed its accuracy, the updated draft certificate along with the certification test report will be forwarded to UCA. The international organization will examine all materials and, if its resolution is positive, register the certificate in the UCA database and DNV GL register.

Positive test results grant the applicant a right to:

- have the tested unit registered on the UCA website;
- have the tested unit registered in the DNV GL register that is accessible to third parties. The register contains a list of equipment items and suppliers with IEC 61850 conformity confirmed by DNV GL;
- use the accompanying test report to provide detailed documentation to third parties or buyers of the product.

During the period of cooperation of JSC R&D Center at FGC UES with DNV GL, secondary switching equipment (WAC terminals, connection controllers) of more than 10 Russian companies was certified (Fig. 4, Table 1).

Devices of all levels connected to the communication network are components of communication interaction along with the network equipment

4. Testing infrastructure of JSC R&D Center at FGC UES

Today, JSC R&D Center at FGC UES is working on expanding its testing infrastructure in order to carry out functional tests on automated systems and units of power facilities based on the Digital Substation technology. It aims to create a full-scale testing cluster consisting of a testbed for information technology systems of a substation, comprising samples of products from leading plants in Russia and worldwide and a dedicated DSS TS communication link.

To ensure DSS information security, a substation cybersecurity testbed has been created, with a mission to research information security, check the data protection means for compatibility with process automation TTS specimens, carry out personnel training, and analyze the software security of the secondary equipment utilized at an electrical grid facility (Fig. 6).

CONCLUSION

JSC R&D Center at FGC UES has established a real Competence Center in the field of development of the Digital Substation technology. The Center is a platform for specialists and experts in the Digital Substation technology and a site for development of measures and testing of engineering solutions for implementation of the DSS technology in power facilities with minimal costs, with implementation of the experience of best research organizations:

1. The DSS Competence Center of JSC R&D Center at FGC UES is reinforced with a test site built at the operating experimental substation, enabling field tests and real-time simulations of the disturbances that occur in the adjacent electrical network and at the facility itself. This, in its turn, makes it possible to considerably shorten the time of implementation of new technologies when testing the functional performance of equipment and to analyze an array of options of LAN for substations of any voltage class.
2. The active test site created by JSC R&D Center at FGC UES enables simulation of disturbance impacts applied to the equipment under test to verify the claimed technical characteristics of secondary equipment designed for the DSS technology implementation.
3. The R&D efforts made during the establishment of the DSS TS for the purpose of designing and test-

ing pilot specimens of equipment operating in accordance with IEC 61850 laid the basis for designing core commercial equipment.

4. End-to-end functional tests of DSS automation and protection systems performed at the DSS TS allow obtaining standard engineering solutions for the implementation of the DSS technology at utilities of various voltage classes, which may considerably shorten the time of trial operation. Furthermore, the results of end-to-end testing and the proven standard solutions lead to more affordable design solutions with no need to create any additional experimental 'digital' circuits of secondary switching equipment at pilot power facilities.
5. JSC R&D Center at FGC UES, by order of PJSC FGC UES, is working on developing standard technical solutions for digital substations with different degrees of automation using computer-aided design systems aimed at reducing the cost and the lead time of utility designs.
6. The most important practical component of the DSS TS activity is certification of secondary equipment of Russian companies for IEC 61850 conformance and assistance with obtainment of a UCA level A certificate to promote their products on international markets.
7. A promising application task of the DSS TS is to use the site as a testbed for ensuring information security of power facilities. A trial specimen of the DSS cybersecurity software and hardware package was tested at the DSS TS in 2017.
8. Activities planned at the DSS TS include training workshops and conferences for industry-related personnel with utilization of the test site's resources and expansion of its functional capacities. The Second International Conference "Digital Substation. Standard IEC 61850" is to be held in 2019 (hosted by JSC R&D Center at FGC UES, jointly with DNV GL, and with support from CIGRE Russian NC).

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COMPANIES THAT CERTIFIED THEIR SECONDARY SWITCHING EQUIPMENT FOR CONFORMANCE TO IEC 61850-8-1 SERVER (ED. 1/2)

No. no.	Year	Company	IEC 61850-8-1 server (Ed. 1/2)	Number of terminals	UCA certificate
1	2015	LLC Energoservice (Arkhangelsk)	1	1	Level A
2	2015	Ltd EKRA Research and Production Enterprise (Cheboksary)	1	1	Level A
3	2015	JSC MRZ (Moscow)	1	1	Level A Level A
4	2015	JSC IC Bresler (Cheboksary)	1	2	Level A
5	2015	LLC NPP Bresler (Cheboksary)	1	1	Level A
6	2015	JSC Radius-Avtomatika (Zelenograd)	2	1	Level A
7	2016	JSC NIPOM (Nizhni Novgorod)	1	1	Level A
8	2016	JSC CHEAZ (Cheboksary)	2	1	Level A
9	2016	JSC Electropribor (Cheboksary)	1	3	Level A
10	2016	JSC Tecon-Engineering (Moscow)	2	1	Level A
11	2017	Ltd EKRA Research and Production Enterprise (Cheboksary)	2	3	Level A
12	2017	LLC PLC Technology (Moscow)	2	1	Level A
13	2018	LLC Svey (Yekaterinburg)	2	1	Level A
14	2018	JSC VNIIR (Cheboksary)	1	1	Level A

Table 3